

## Chapter 3

# METHODS FOR DEVELOPING MINIMUM FLOW CRITERIA

Minimum flow criteria developed for the Loxahatchee River and Estuary were based on six primary sources of information as follows:

1. Development of a “Valued Ecosystem Component” (VEC) approach for establishing the minimum flow based on cypress forest/mangrove distribution
2. Review of the available literature
3. Analysis and interpretation of historical (1940s) and present day (1995) aerial photography to document changes in river vegetation through time.
4. Review of the results from a recent vegetation survey of the NW Fork of the Loxahatchee River (November 2000)
5. Statistical analysis of flow versus salinity data collected from the NW Fork of the river from 1994 –2000
6. Development and application of an estuarine hydrodynamic model to explore the relationship between freshwater flows and salinity within the river and downstream estuary.

## VALUED ECOSYSTEM COMPONENT (VEC) APPROACH

A resource-based management strategy similar to the Valued Ecosystem Component (VEC) approach developed by the U.S. Environmental Protection Agency as part of its National Estuary Program (USEPA 1987) was applied to the Loxahatchee River and Estuary. There are several definitions of a Valued Ecosystem Component in the literature. Some examples of definitions are as follows:

1. *“A resource or environmental feature that is important (not only economically) to a local human population, or has national or international profile, or if altered from its existing status, will be important for the evaluation of environmental impacts of development and the focusing of administrative efforts”*
2. *“Any part of the environment that is considered important by the proponent, public, scientists and government involved in the assessment process. Importance may be determined on the basis of scientific concern or based on cultural values”.*

For the purposes of this study, the VEC approach was based on the concept that management goals for this system can best be achieved by providing suitable environmental conditions for selected key species or key groups of resident species. In this case, the key species

identified to be protected against significant harm is the bald cypress, *Taxodium distichum*, present within the upstream fresh water portion of the river.

The remaining bald cypress community located within the upstream area of the NW Fork of the Loxahatchee River is an important component of the regional ecosystem. The cypress community structure is complex, comprised of low understory groundcovers and shrubs, medium height sub-canopy shrubs and hardwoods, and high canopy hardwoods, palms and bald cypress, including a number of trees within the 300-400 year old range. The high canopy supports a wide variety of epiphytic plants such as ferns, bromeliads and orchids. This community provides a number of important water resource functions for ecosystem: (1) leaf litter and organic detritus form the basis of the food chain for upstream river system, (2) the cypress community also helps to stabilize the river shoreline and soils to prevent erosion, and provides habitat for many plant and animal species, a number of which are rare or endangered. The cypress swamp supports a diverse population of animals, including many that also utilize the surrounding upland and estuarine habitats. Wetland areas similar to this cypress swamp support both high wildlife density and diversity (Ewel 1990).

The long-term decline in the distribution and health of the cypress river-swamp community within the mid to upstream portion of the Northwest Fork of the River appears to be linked to saltwater intrusion during dry periods. These periodic episodes of increased salinity appear to be the result of hydrologic alterations of the river and its upstream watershed as well as past dredging activities within the estuary and Jupiter inlet. Combined these factors have resulted in reduced freshwater flows to the River, lowering of the groundwater table and increasing the frequency that cypress river-swamp community is exposed to saltwater intrusion. Sufficient freshwater flows are required during the dry season to protect the remaining cypress community from further degradation and loss of natural function.

The VEC approach assumes (a) that environmental conditions suitable for VEC will also be suitable for other desirable species present within the ecosystem; and, (b) that enhancement of VEC will lead to enhancement of other species. Through this overall strategy, management objectives will be attained by providing a minimum flow that will protect the VEC against significant harm.

The VEC approach was applied to the Loxahatchee River and Estuary based on the following scientific assumptions: The last remaining stands of Bald cypress forests occur within upstream areas of the river that largely dominated by freshwater. This freshwater condition is maintained by sustained flows delivered to the river through the Northwest Fork and its three primary tributaries (Cypress Creek, Hobe Grove Ditch and Kitching Creek). When flow rates are insufficient to maintain a freshwater head within the mid to upstream areas of the river, the freshwater-saltwater interface moves upstream, some times as far as 10 miles upriver impacting remaining Bald cypress habitat. Over time, increased periods of high salinity results in the dieback of cypress and other freshwater dependent species, creating space for the subsequent colonization by saltwater tolerant mangroves. For this reason, the cypress community was identified as the VEC of choice to be protected from significant harm during low flow periods.

## LITERATURE REVIEW

Pursuant to Section 373.042, F.S., the District is required to utilize best available information to establish the MFL. In this regard the District performed an intensive review of the existing literature to (1) identify the water resource functions of the river and estuary that need protection, and (2) to determine the technical relationships among flow, salinity, river hydrodynamics that impact key indicator communities, or species present within the NW Fork of the river. Specifically, the review involved: (a) identifying individual species or biological communities that could serve as useful indicators, targets, or criteria for determining a minimum flow for the NW Fork and the estuary; (b) determining how these indicator species or indicator communities have been impacted by structural and/or hydrologic alterations of the river and upstream watershed; (c) reviewing the previous experiences of the SFWMD and other water management districts with respect to the establishment of MFLs for surface water bodies; and (d) evaluating the Valued Ecosystem Component (VEC) approach to establish a MFL for a tidal river. The following is a summary of the information that was reviewed and evaluated for development of the MFL for the Loxahatchee River/Estuary system.

- The library card catalogs of the SFWMD, University of Miami (UM) and Florida Atlantic University were reviewed for relevant citations. In addition, Internet searches were performed using open-access general searches and search engines. Individual key words and combinations of key words were searched to cover: Loxahatchee River, cypress, mangroves, seagrasses, vegetation, macro-invertebrates, benthic fauna, submerged aquatic vegetation, forested freshwater wetlands, tidal river, estuary, hydrology, freshwater flow, salinity tolerance, salt intrusion, ground water, and soil salinity.
- A literature review was conducted utilizing the *Bibliography on Water Resources in the Loxahatchee River Watershed* (Dent, 1997).
- Information was also obtained through dialogue with the Loxahatchee River Environmental Control District, Jonathan Dickinson State Park, and the UM Department of Biology.
- An additional literature review was conducted to identify the: 1) key species or groups of organisms that may benefit from utilizing cypress swamp and/or cypress riverine wetland communities of the NW Fork; 2) life history of bald cypress; 3) salinity tolerance of bald cypress; and 4) historic wetland vegetation changes on the NW Fork. **Appendix A** provides a bibliography all the documents reviewed by staff as part of the literature review.

## REVIEW OF HISTORICAL AERIAL PHOTOGRAPHY

District staff utilized existing historical aerial photography to compare changes in the distribution and abundance of vegetation communities along the floodplains of the Northwest Fork of the Loxahatchee River over time. Black and white aerial photos taken in 1940 were compared to present day color infrared photography taken in 1995 to quantify changes in the coverage of major vegetation communities. Special focus of this investigation was to assess the

losses and gains in the distribution and abundance of freshwater hardwood (cypress) communities and mangrove communities along the river corridor over time. In addition, District staff re-examined several sites along the NW Fork of the river originally documented by Alexander and Crook (1975) during their investigation of long-term changes in South Florida vegetation communities. The purpose of this work was to document changes in vegetative cover over time and correlate these changes to major events or changes within the watershed.

The 1940 aerial black and white photos were obtained from the National Archives (College Park, Md.). The 1995 color infrared Digital Ortho Quad photographs were obtained from National Aerial Photography Program. Groundtruthing and field observations were conducted by District staff to validate the signatures of the current plant communities found along the floodplain of the river. **Appendix B** of this report provides the reader with a detailed summary of the methods, results, and river vegetation maps developed as part of this investigation.

## VEGETATION SURVEY OF THE NW FORK

A survey of the vegetation along the banks of the Northwest Fork of the Loxahatchee River and Kitching Creek was conducted by the District in order to document differences in the plant community associated with the saltwater-freshwater gradient. This information will also be useful as baseline data for comparison with future vegetation surveys in these areas.

The vegetation survey along the River included seventeen sites and was conducted on November 14, 2000 from river mile 5.5 upstream to near Trapper Nelson's located in at river mile 10.5 in Jonathan Dickinson State Park. An additional vegetation survey was conducted along Kitching Creek on November 14 and 28, 2000 and included ten sites (**Figure 11**). All vascular plant species observed along the embankment within 100 ft. of a site were recorded. Abundance estimates were also recorded and were defined by the following scale:

- Abundant = dominant species with widespread distribution, a primary component of the plant community
- Common = sparse to moderate density with widespread distribution, but not a dominant component of the plant community
- Sparse = occasional individuals throughout or in sparse localized populations; not a significant component of the plant community
- Rare = one to few individuals of localized distribution

These data were recorded on field data sheets, entered into a spreadsheet program, and analyzed for trends. Linear regression analyses was used to determine significant correlations between dominant species and salinity conditions along the river gradient, as well as for inter-specific relationships. Results are presented in Chapter 4 of this document.



Figure 11. Location of 27 vegetation sampling sites located on the NW Fork of the Loxahatchee River, November 2000.

## ESTABLISHMENT OF GPS COORDINATES FOR LOCAL FEATURES AND STUDY SITES

### GPS Coordinates for River Miles

For previous Loxahatchee River studies, river miles were set up along the length of the NW Fork as reference points for documenting water quality and biological changes along the River. However, District review of these studies revealed a number of differences in the locations of specific river miles as recorded in each study. These differences may be the result of differences in mapping methodologies; specifically, measuring the river channel utilizing: 1) scaled aerials/maps; 2) how each author measured the meandering river ox-bows, and 3) whether or not the man-made river gaps, or short-cuts through the mangrove areas were included in their calculation of river miles.

For the purpose of documenting flow, salinity and vegetation changes along the NW Fork, the District established revised river mile locations using 1-meter Digital Ortho Quarter

Quads, (DOQQ's) as a base map. The DOQQ's are at a scale of 1:12000 and have been used as the basemap for a large majority of District mapping efforts.

Utilizing ArcView, the starting point/river mile 0 was located at the mouth of the Jupiter Inlet. Subsequent river mile locations were measured through the centerline of the main channel/tributary, incorporating the meandering ox-bows. The river mile locations were processed into an ArcInfo point coverage, lox\_pts, with the following attributes:

*RIVER\_MILE*

*X-COORD*

*Y-COORD*

## GPS Coordinates for Vegetation Points/Stations

The river mile locations were established and processed by the District into a format for downloading the information into a Global Positioning Satellite (GPS) unit, for navigational purposes. The vegetation points/stations along the NW Fork were established in relation to the identified river mile locations. Using the river mile data in the GPS unit as a navigator, a boat was steered along the main channel/tributary (through the meandering ox-bows) to the appropriate river mile(s). Each vegetation station was first located visually in comparison to a 1997 aerial photograph and the point/station location of the site was recorded with the GPS unit. The GPS unit that was utilized, requires points at sub-meter accuracy.

Once all of the vegetation point/station locations were recorded into the GPS unit, the data was downloaded and processed into an ArcInfo coverage with the following attributes:

<i>MAX_PDOP</i>	}	Attributes established byGPS unit
<i>GPS_DATE</i>		
<i>GPS_TIME</i>		
<i>DATAFILE</i>		
<i>UNFILT PO</i>	}	
<i>HORZ_PREC</i>		
<i>LONGITUDE</i>		
<i>LATITUDE</i>		
<i>SITE</i>		

All GIS data created or used by the District is stored in State Plane Coordinates, using the East zone, and the 1983 datum.

## DEVELOPMENT OF FLOW/SALINITY RELATIONSHIPS

### Monitoring Sites and Sampling Protocol

In an effort to define the relationship between freshwater flow and the movement of the saltwater up and down the NW Fork of the Loxahatchee River, statistical analyses of historical river flow and salinity data were conducted. Historical flow data were obtained from the Lainhart Dam, located on the Loxahatchee River near Jupiter, Florida. Daily stage and flow data were obtained from the SFWMD's DBHYDRO data retrieval system for the Lainhart Dam for the period of record of January 1994 through July 2000. The collected stage data were converted to flow (cubic feet per second) using a rating curve developed by the District. This curve was developed based on a 1994 re-calibration analysis of the Lainhart Dam.

Historical flow and salinity data have been periodically collected for the Loxahatchee River and estuary since the 1970's (e.g., Rodis 1973, Chiu 1975, Russell and McPherson 1984, Mote Marine Laboratory 1990b, Dent 1997). The January 1994 – July 2000 period of record was selected because it brackets the period when recent changes were made to the river channel. Several river channels (or gaps) were created over the past 25 years to provide shorter routes for boaters. Unfortunately, these "shortcuts" bypassed historic river meander flow patterns and provided a more direct path for the upstream migration of salt water. In 1997, the Jupiter Inlet District constructed a number of earth and rock dams to seal off these short cuts and reestablish historical flow routes for the river. Salinity studies conducted by the Loxahatchee River Environmental Control District (LRD) demonstrated that these construction activities resulted in lower salinity levels upstream of the closures (Dent, 1997). The 1994-2000 period of record reflects these hydrologic improvements to the river as well as the 1994 re-calibration of flow data obtained from the Lainhart Dam. This time period also includes a wide range of both high, average, and low flow periods and also corresponds to the most recent set of salinity values collected for the river by the LRD.

Historical salinity data for five river sampling sites (**Figure 8**) were obtained from water quality surveys conducted by the LRD for the period of record January 1994-July 2000. Water quality station # 63 is located at a depth of about 3.0 meters between mid-channel and the southern shore at approximately SFWMD river mile 6.5 in the vicinity of the south boat ramp for Jonathan Dickinson State Park. This station was used previously by the U.S. Geological Survey, the SFWMD, and the LRD to record salinity levels within the river. Water quality station # 64 is located at SFWMD river mile 7.7, or about 0.5 mile upstream of the Jonathan Dickinson State Park canoe concession area. The site is located near the eastern shore on the outside of a river bend where the depth exceeds 4.0 meters. Water quality station # 65 is located at SFWMD river mile 8.6 above the confluence of Kitching Creek and the NW Fork of the River. The depth at Station # 65 is 3.5 meters and sampling was conducted near the northern shore where the deepest portion of the channel is located. Water quality station # 66 is located at SFWMD river mile 9.4, while Water quality station # 67 is located at SFWMD river mile 10.5, approximately 0.1 mile downstream from the Trapper Nelson Interpretative Site. Water quality stations #66 and #67 were temporary monitoring sites set up to sample salinity levels during extremely low flow periods. During average and above average rainfall periods these sites receive considerable flow

and were assumed not to be influenced by saltwater during normal and above normal rainfall periods.

For each station, the specific water quality sampling point was marked by a permanent buoy. Water quality samples were collected approximately one meter above the channel bottom using a sampling tube anchored to the bottom by a 5-gallon bucket filled with concrete. In areas influenced by saltwater, samplers were retrieved every two weeks, cleaned and calibrated. In areas that were predominately freshwater, samplers were deployed for longer periods of time (15-30 days). Samplers were deployed primarily during dry periods when it was known that salt water had the potential to move upstream within the river system.

Sampling equipment consisted of three Hydrolab® Datasonde Model #3 monitoring probes and a data logger unit. This equipment provided readings for salinity (specific conductivity) dissolved oxygen, depth, and other parameters. Data were recorded at one half-hour intervals (48 readings/day). These data were electronically stored in the data logger until the unit was retrieved and information downloaded to a personal computer. Under normal operating conditions, the probes were placed *in situ* for a period ranging from 15 to 30 days, then removed for a few days to download data and re-calibrate and service the monitoring probe. Data collected were edited according to quality control standards. In this study, the highest salinity reading for each day was used in the statistical regression analyses discussed below. This value was chosen because it represents the maximum extent of saltwater contamination at each site for that particular day.

## Statistical Analyses

Statistical trend analyses were conducted for the daily flow and salinity data collected from each of the five water quality monitoring sites (water quality stations # 63, 64, 65, 66 and 67). Average daily flow rates over the Lainhart Dam were plotted (x axis) against maximum daily bottom salinity values (y axis) in an Excel spreadsheet. These plots were then subjected to a number of trend analyses (e.g., linear regression, power curve, exponential) to obtain the best fit. These statistical relationships and graphical plots were used to estimate the amount of flow over the Lainhart Dam needed to maintain an average bottom salinity of 2 parts per thousand (ppt) at each water quality monitoring station. The bottom salinity of 2 ppt was selected as the cutoff level for two reasons:

1. Russell and McPherson (1984) reported that a relatively, well-defined saltwater wedge occurs in the NW Fork of the river. The upstream tip of this wedge is defined by a salinity of 2 ppt occurring near the bottom. Using this value, this study identified the approximate upstream location of the saltwater wedge under different flow conditions.
2. Results of the literature review (see **Appendix A**) indicate that this level of salt has a toxic effect on the growth and reproduction of both cypress and hardwood tree species (as well as other forms of freshwater aquatic life) that comprise ecologically significant communities within the upstream portion of the river.

Estimates of dry and wet season flows for Kitching Creek, Cypress Creek, and Hobe Grove Ditch used in this study were primarily derived from USGS data (Russel and McPherson, 1983).

Results of the trend analyses showed that a power curve produced the best fit of data for Water quality station #63 (the most variable site) and exponential curves provided the best fit for stations #64 and #65. Results are presented both in terms of salinity levels achieved after closure of the river channel gaps (January 1997 – July 2000), as well as for the entire data set 1994-2000. Results are summarized in Chapter 4 and details of the trend analyses are provided in **Appendix D**. These results are considered to provide a conservative estimate of the minimum flow conditions that are required to maintain the 2 ppt bottom salinity wedge at each river station.

## DEVELOPMENT OF HYDRODYNAMIC-SALINITY MODEL

The upstream migration of salt water into the historic freshwater reaches of the Loxahatchee River has altered the floodplain cypress forest community along the Northwest Fork and some of its tributaries. A hydrodynamic/salinity model was developed to study the influence of freshwater input on the salinity conditions in the river and downstream estuary. The purpose of this modeling effort was to predict salinity conditions at various points in the river and downstream estuary with respect of freshwater inflow rates and tidal fluctuations.

### Model Description

The software used in the development of Loxahatchee River Hydrodynamics/Salinity Model were computer programs RMA-2 and RMA-4 that were developed by Army Corps of Engineers (USACE, 1996). RMA2 is a two dimensional depth averaged finite element hydrodynamic numerical model. It computes water surface elevations and horizontal velocity components for subcritical, free-surface flow in two dimensional flow fields. RMA2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows. Friction is calculated with the Manning's or Chezy equation, and eddy viscosity coefficients are used to define turbulence characteristics. Both steady and unsteady state (dynamic) problems can be analyzed.

The program has been applied to calculate water levels and flow distribution around islands; flow at bridges having one or more relief openings, in contracting and expanding reaches, calculating flows into and out of off-channel hydropower plants, at river junctions, into and out of pumping plant channels; circulation and transport in water bodies with wetlands; and general water levels and flow patterns in rivers, reservoirs, and estuaries.

The water quality model, RMA4, is designed to simulate the depth-average advection-diffusion process in an aquatic environment. The model is used for investigating the physical processes of migration and mixing of a soluble substance in reservoirs, rivers, bays, estuaries and coastal zones. The model is useful for evaluation of the basic processes or for defining the effectiveness of remedial measures. For complex geometries, the model utilizes the depth-averaged hydrodynamics from RMA2.

The formulation of RMA4 is limited to one-dimensional (cross-sectionally averaged) and two-dimensional (depth-averaged) situations in which the concentration is fairly well mixed in the vertical direction. It will not provide accurate concentrations for stratified situations in which the constituent concentration influences the density of the fluid. The preliminary results indicated that the model was able to predict the salinity fluctuation driven by the tide cycle and the influence of freshwater input on the salinity regime in the river.

## **Model Calibration and Verification**

The model was calibrated and verified against field data that were collected from January to June of 1999. Then the model was applied to scenarios that were proposed by the study team. Two series of model simulations were requested. The first simulation (Simulation #1) included flows from the Northwest Fork of the River and its three tributaries based on flow ratios established by a previous study. The second model run was named Simulation #2 and contained a minimum amount of freshwater input from the three tributaries. Simulation #1 was used to predict salinity conditions with various freshwater inflow rates that follow historic freshwater input patterns.

Details regarding the basic model setup, data sources and assumptions and calibration/verification process and preliminary model results are presented in detail within **Appendix E** of this report.